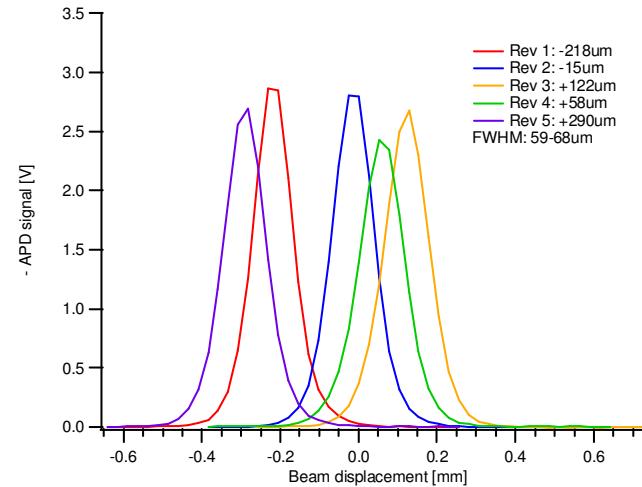
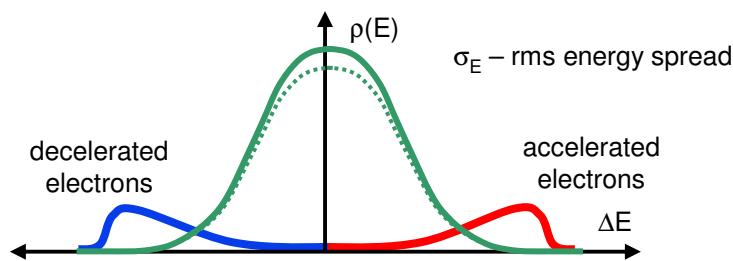


# Bunch kicking at the ALS slicing beamline 6

Marcus Hertlein, Greg Portmann



# Overview



- Beamline 6 – slicing beamline: femtosecond x-ray pulse generation
- Phase space separation
- Gated vs non-gated detectors
- Bunch kicking results
- Slicing at beamline 6

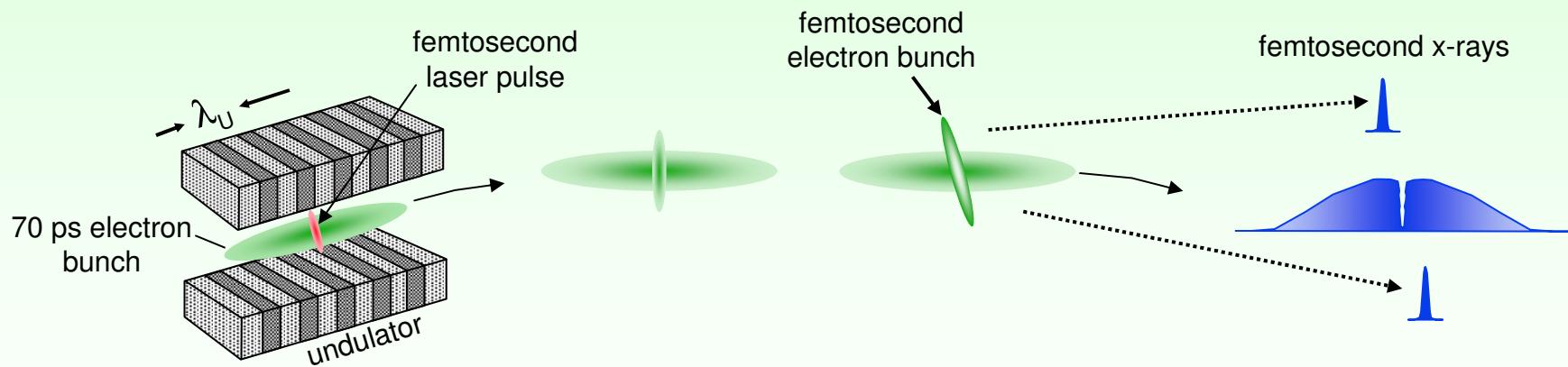
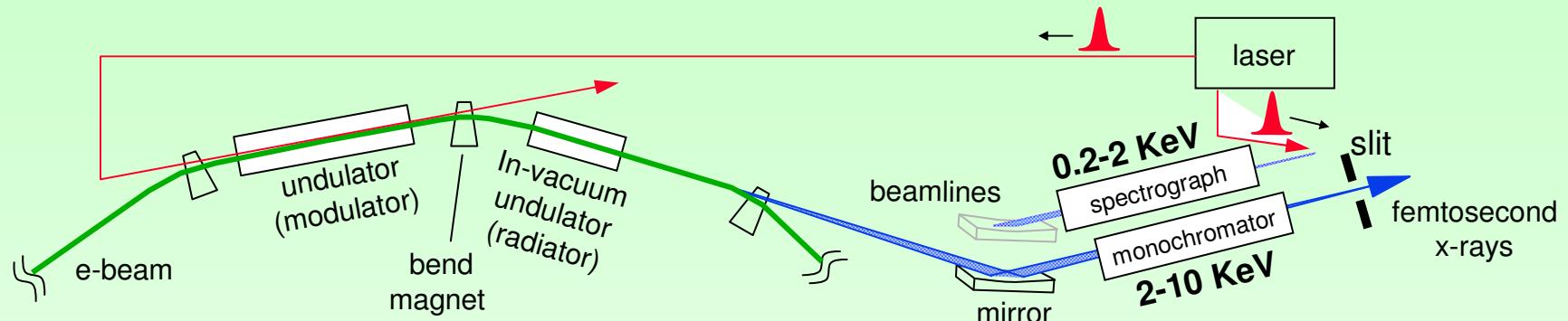
# Sliced x-rays



- x-rays of ~100fs pulse length
- medium high repetition rate (~1kHz)
- tunable (0.2 - 1.2keV; 2 - 10keV)
- available now

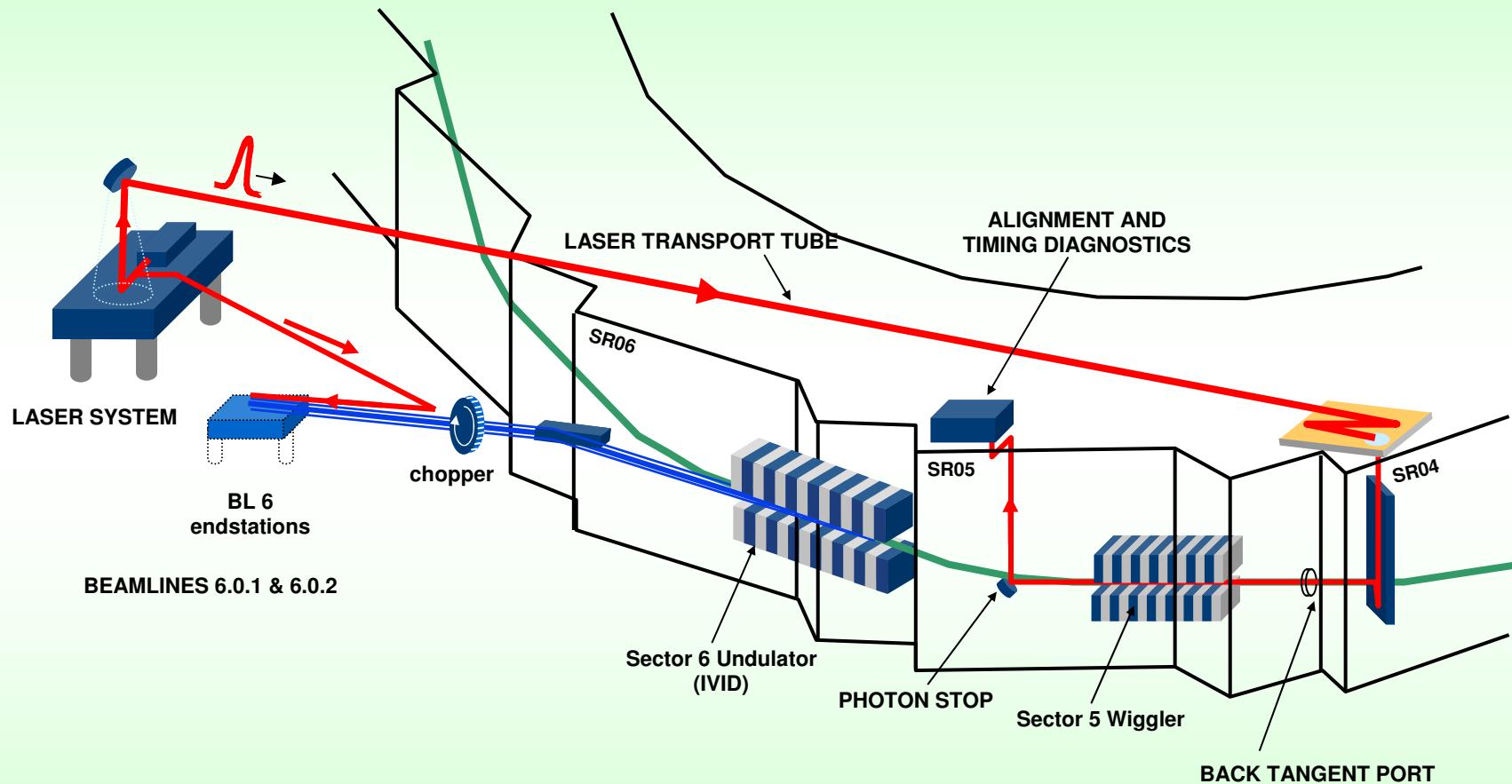
- flux
- background
- currently requires gated detectors

# Generation of Femtosecond X-rays from the ALS

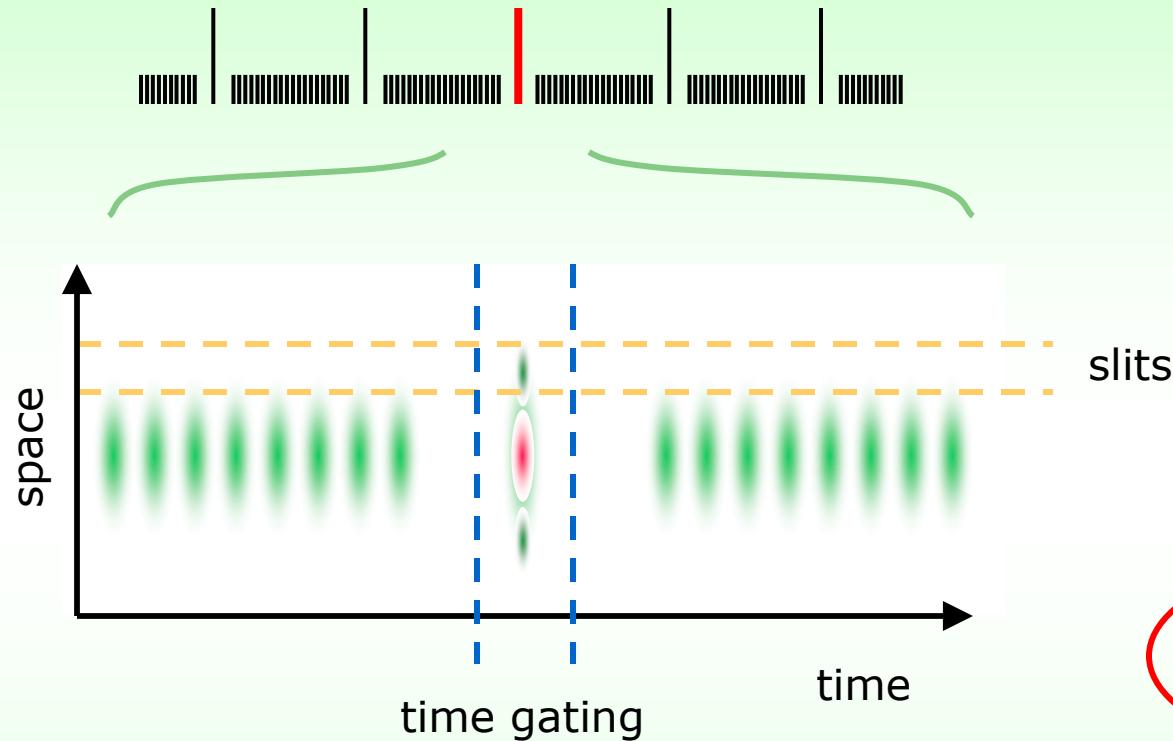


A. Zholents and M. Zolotorev, *Phys. Rev. Lett.*, **76**, 916 (1996)  
Schoenlein et al., *Science*, **287**, 2237 (2000)

# Laser Synchrotron Beam Slicing - Layout



# Phase space separation



## Spatial separation:

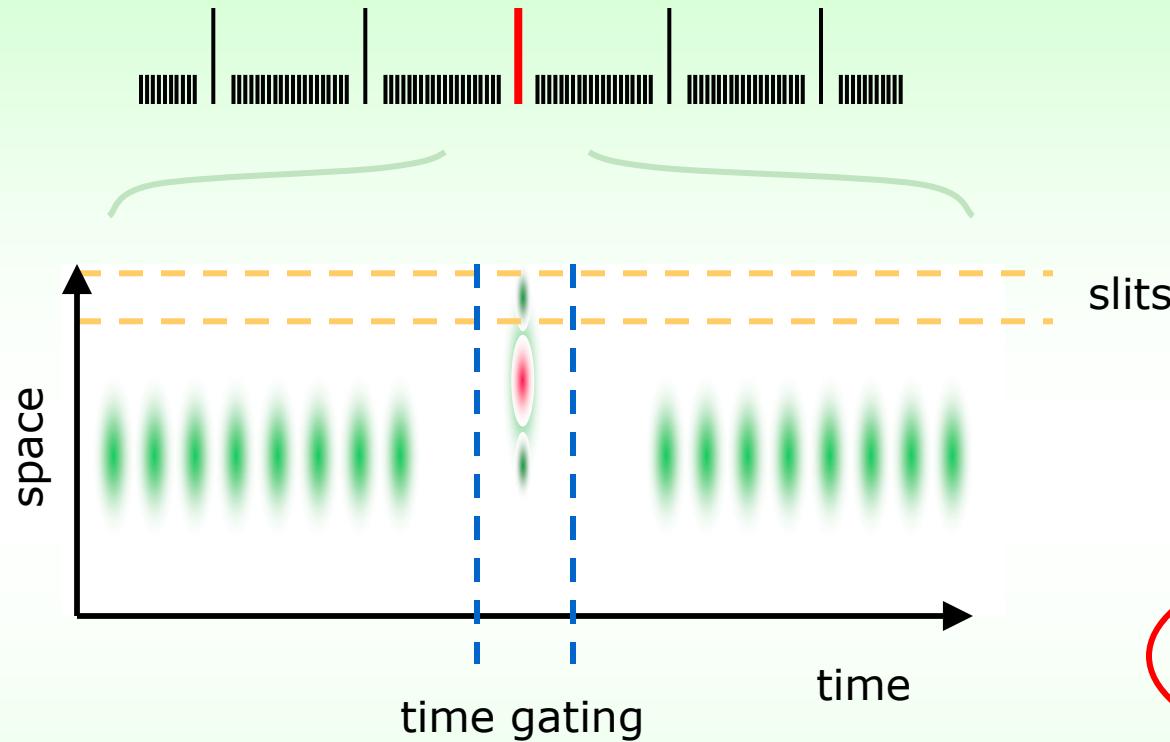
- Separation of fs bunch from main bunch
  - kick from laser ( $\sim \sqrt{I}$ )
  - spatial separation ( $\sim$ dispersion in ring)
  - background of main bunch (spatial profile, scattering from optics)
- Kick of main bunch (separation from multibunches and other camshaft orbits)

## Temporal separation:

- speed of detector system (APD)  
(use of camshaft vs. multibunches)

- number of multibunches contributing to tail (chopper opening time: 4 – 11 $\mu$ s)

# Phase space separation



## Spatial separation:

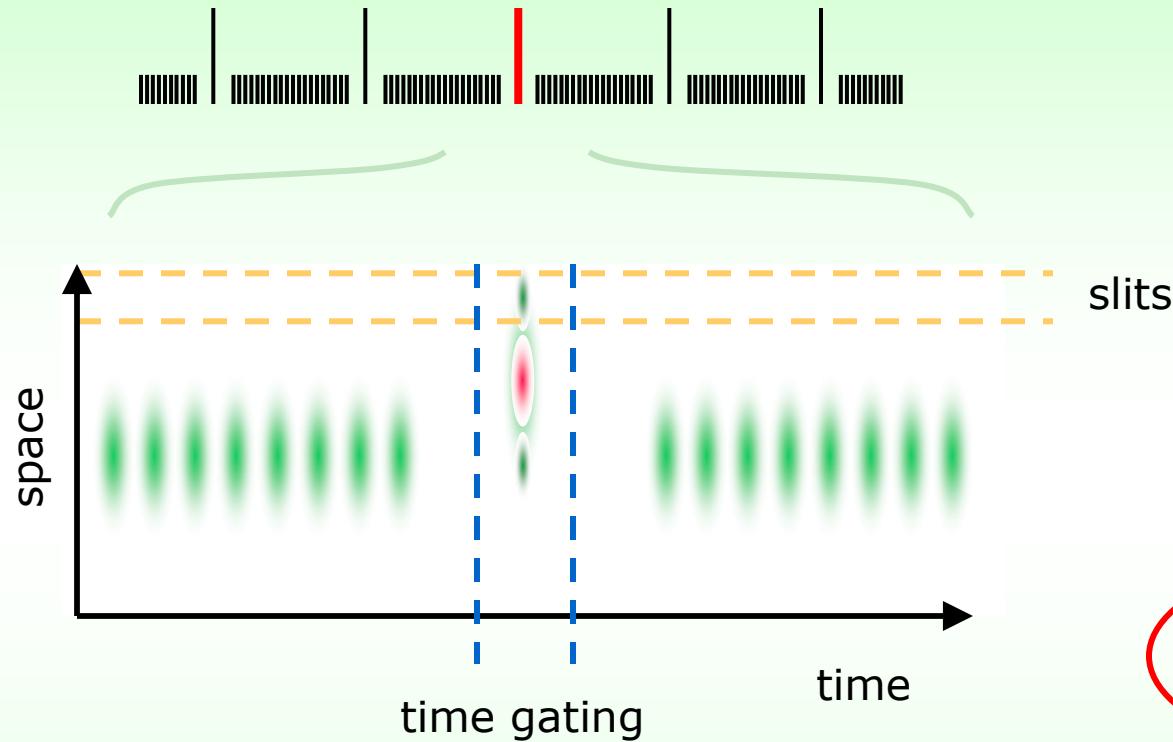
- Separation of fs bunch from main bunch
  - kick from laser ( $\sim \sqrt{I}$ )
  - spatial separation ( $\sim$ dispersion in ring)
  - background of main bunch (spatial profile, scattering from optics)
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## Temporal separation:

- speed of detector system (APD)  
(use of camshaft vs. multibunches)

- number of multibunches contributing to tail (chopper opening time: 4 – 11 $\mu$ s)

# Phase space separation



## Spatial separation:

- Separation of fs bunch from camshaft bunch
  - kick from laser ( $\sim \sqrt{I}$ )
  - spatial separation ( $\sim$ dispersion in ring)
  - background of main bunch (spatial profile, scattering from optics)

- Separation from multibunches and other camshaft orbits (Kick of main bunch)

## Temporal separation:

- speed of detector system (APD)  
(use of camshaft vs. multibunches)

?

- number of multibunches contributing to tail (chopper opening time: 4 – 11 $\mu$ s)

# Gated vs. Integrating Detectors

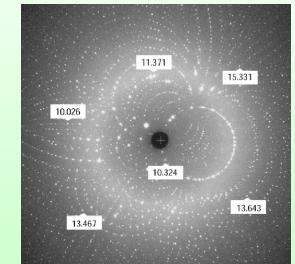
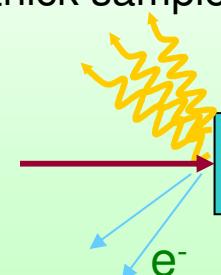
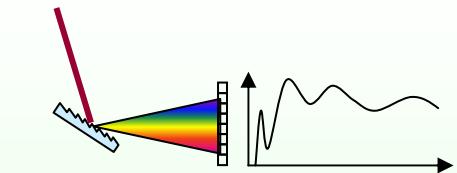


## Gated detectors – currently used

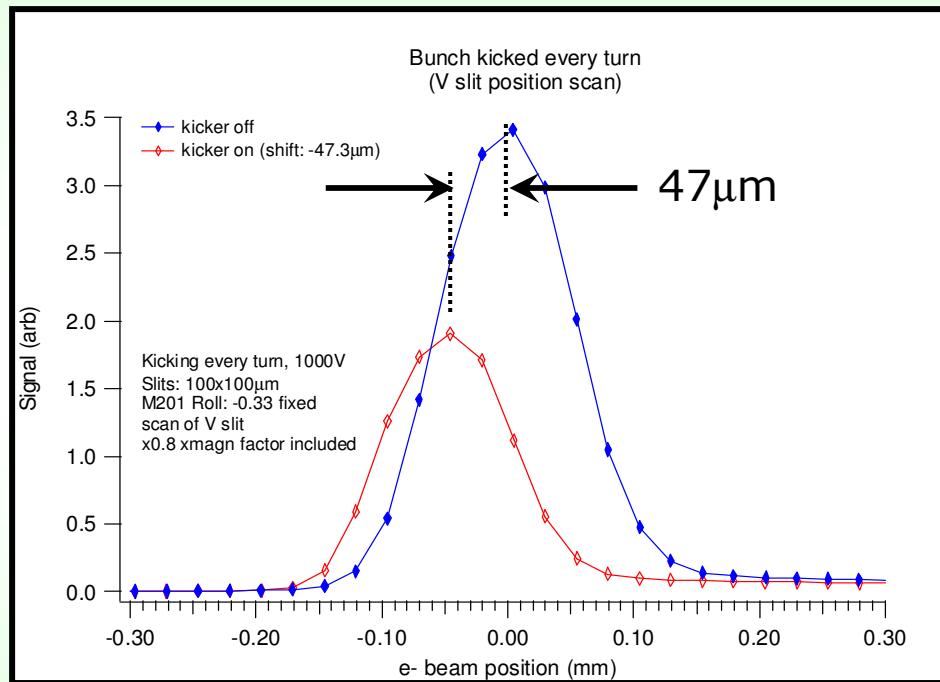
- camshaft – 1 kHz operation (max) – per camshaft bunch  
synchrotron damping  
~10 mA/bunch (assume top-off operation)
- additional camshaft bunches – significant benefit 2x
- multibunch – 10 kHz, at ~1 mA/bunch  
gated detectors – 2 ns resolution  
(significantly more complexity at small flux improvement)

## Integrating detectors

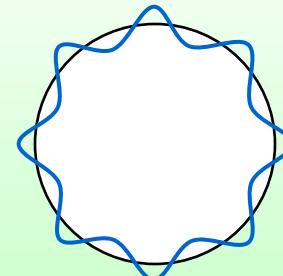
- eliminate need for high-speed (small area) APD detectors  
high speed gatable ~~×~~ high quantum/collection efficiency
- XAS – fluorescence (molecular dynamics – dilute solutions)
- total electron yield or sample current (surface sensitive, thick samples)
- dispersive spectroscopy (soft x-ray, hard x-ray?)  
1D detector with high efficiency (phosphor+CCD)
- 2D high efficiency integrating detectors  
Laue diffraction, powder diffraction, SAX .....



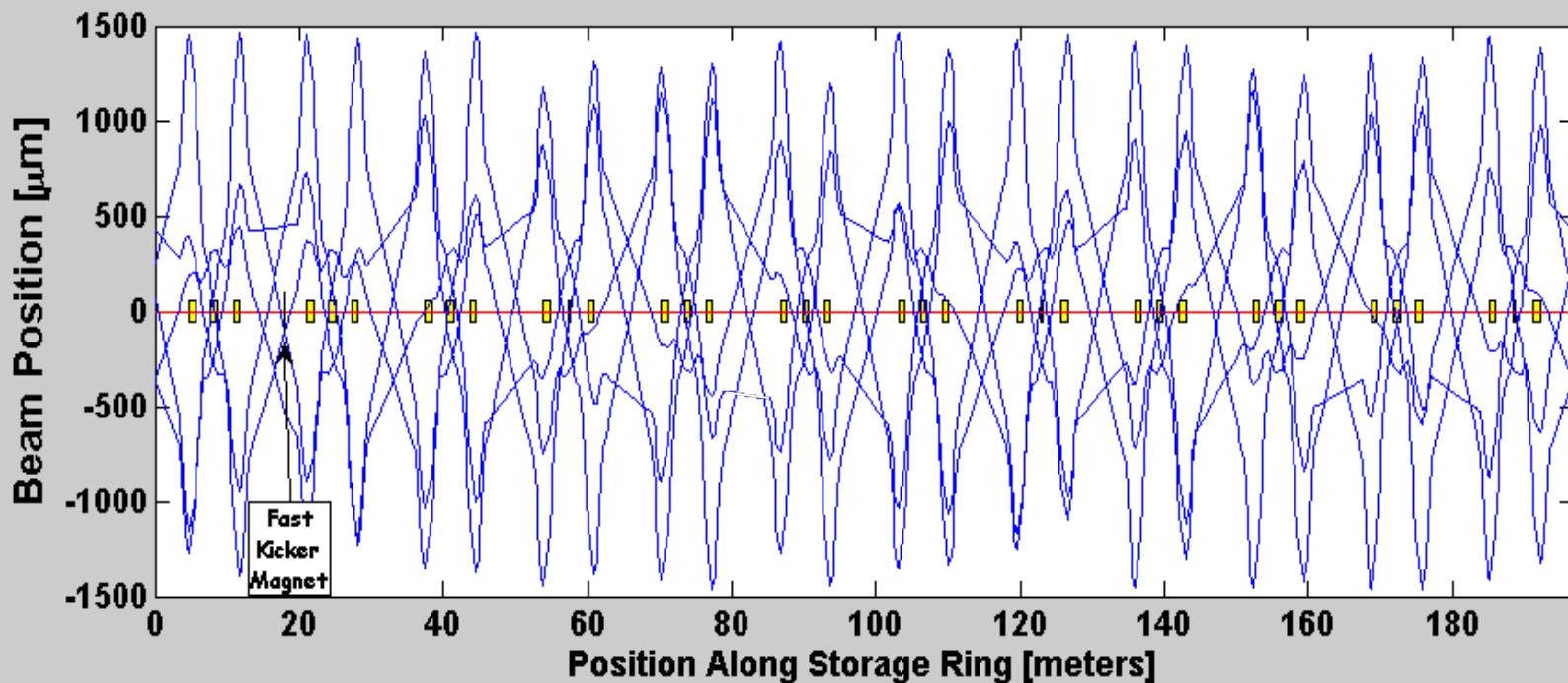
# Bunch kicker: every turn



- Bunch kicking at 1.52MHz (kick every turn)  
Gated detector (APD) only detecting camshaft camshaft displaced vertically by 47 $\mu$ m (< FWHM)



## Single Kicker - Kick Every 5<sup>th</sup> Turn



{ {

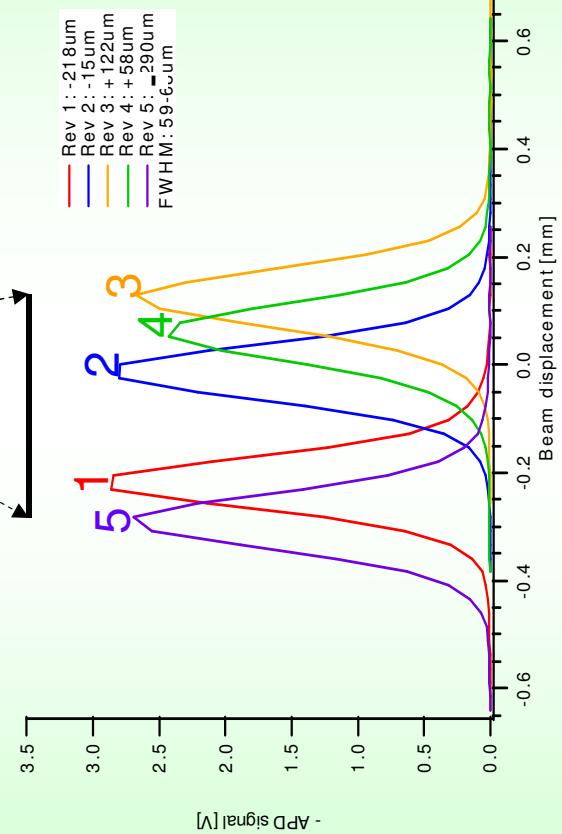
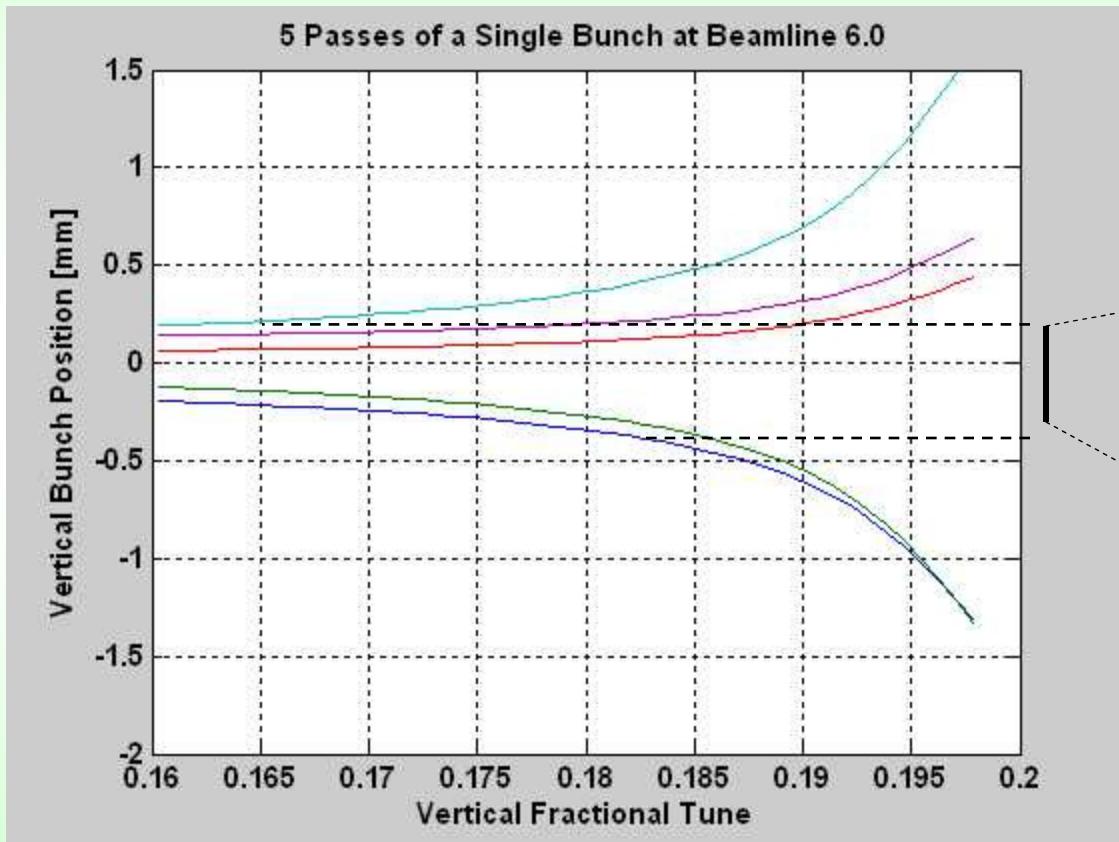
straight 6 –large displacement

{ {  
straight 5 - angular displacement ?  
- laser alignment through W11 ?

# Bunch kicker: every 5<sup>th</sup> turn



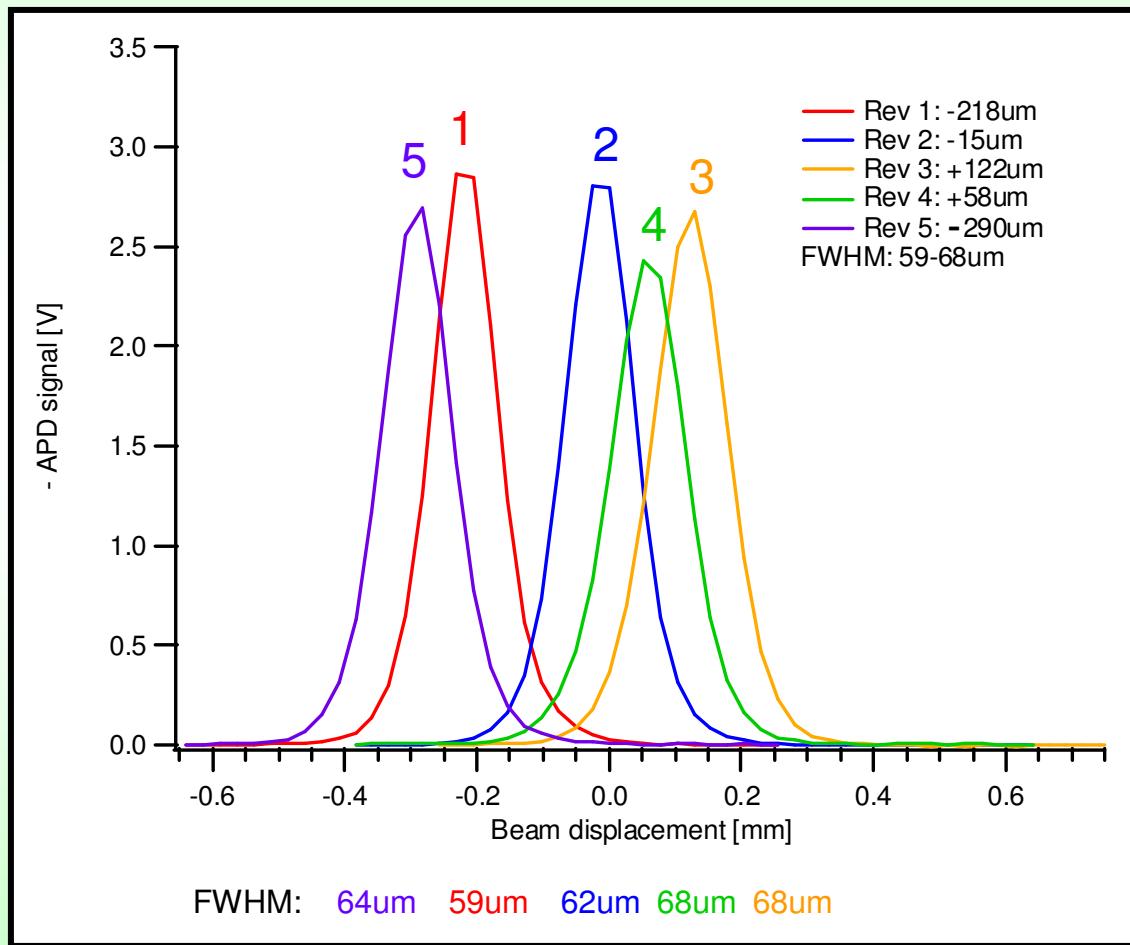
bunch kick rate frequency tune: ~9.165



# Bunch kicker: every 5<sup>th</sup> turn



bunch kick rate frequency tune: ~9.165

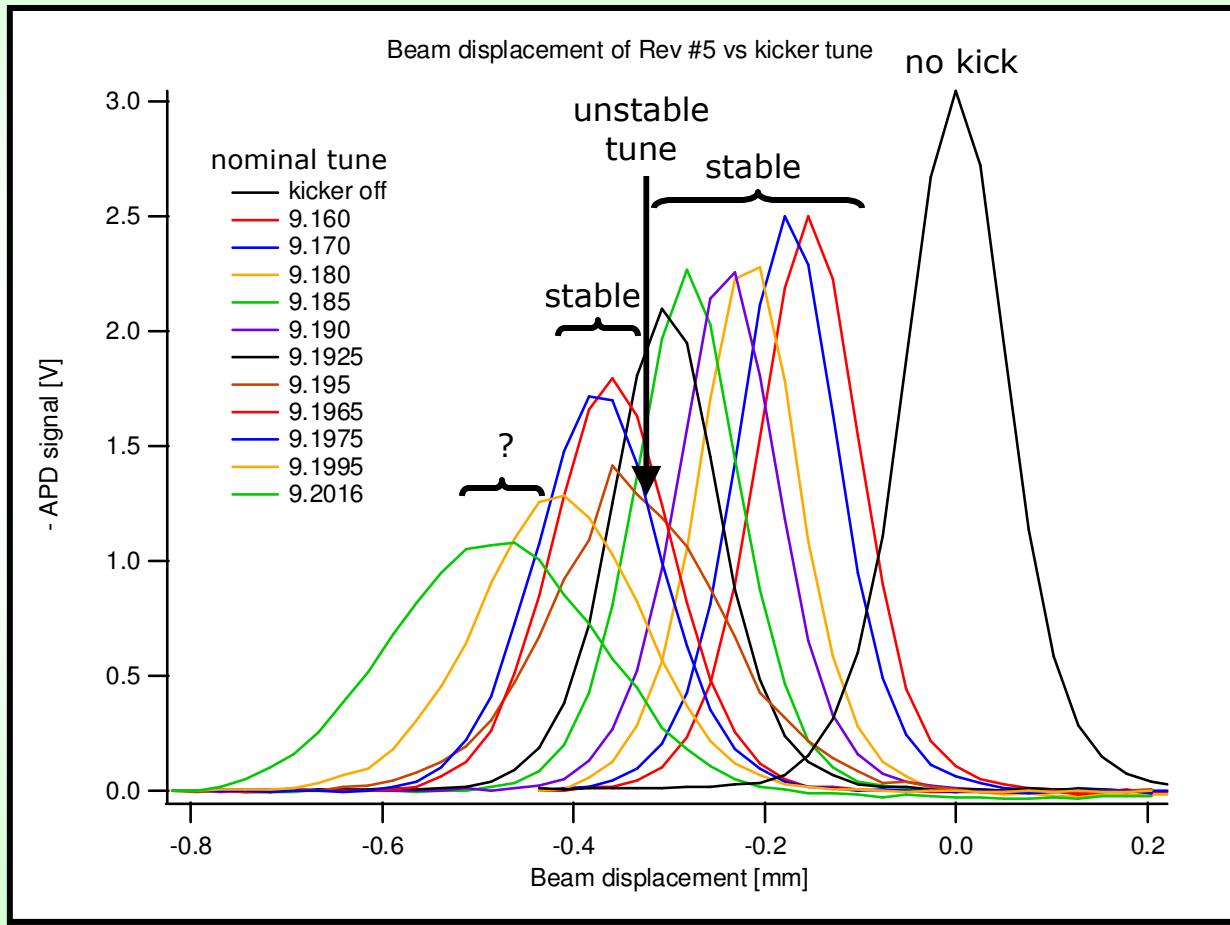


- Bunch kicking at ~304kHz (kick every 5<sup>th</sup> turn)  
beam size not affected by displacement at this tune value

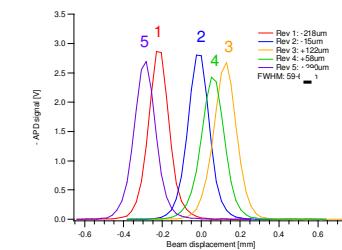
Conditions:

- IVID gap: 19mm
- APD voltage: -170V
- nominal slit size: -0.009mm
- kicker voltage: 1000V
- tune: bot 9.180 nom (~9.165 true)

# Displacements for various kicker tuning



- Revolution 5 is the one with maximum displacement
- signal decrease mostly due to normal beam decay
- beam orbit is unstable at tune 9.195, indicated by increased width and bad profile

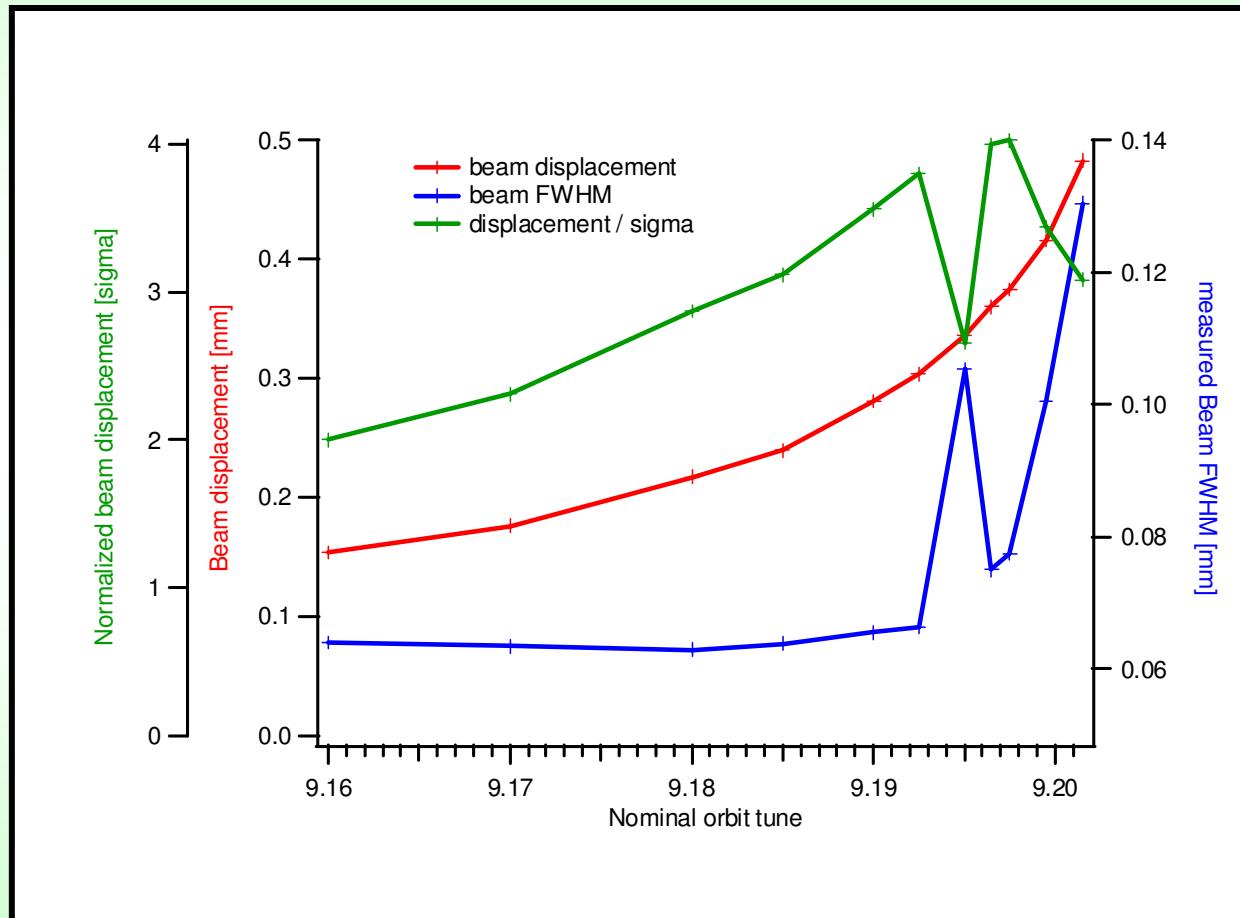


Conditions:

- IVID gap: 19mm
- APD voltage: -170V
- nominal slit size: -0.009mm
- kicker voltage: 1000V

Nominal tune values displayed, actual values are around 0.01 to 0.015 lower

# Displacements for various kicker tuning



- Revolution 5 is the one with maximum displacement
- beam orbit is unstable at tune 9.195, indicated by increased FWHM width
- beam width increases after 9.1965, unclear whether orbit is unstable or beam is larger
- beam displacement approaches  $4\sigma$

## Conditions:

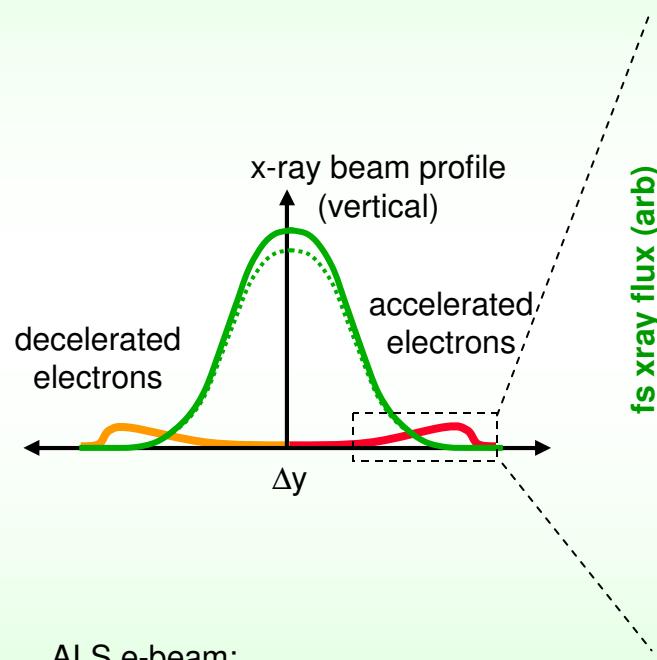
- IVID gap: 19mm
- APD voltage: -170V
- nominal slit size: -0.009mm
- kicker voltage: 1000V

Nominal tune values displayed, actual values are around 0.01 to 0.015 lower

# Femtosecond slicing efficiency

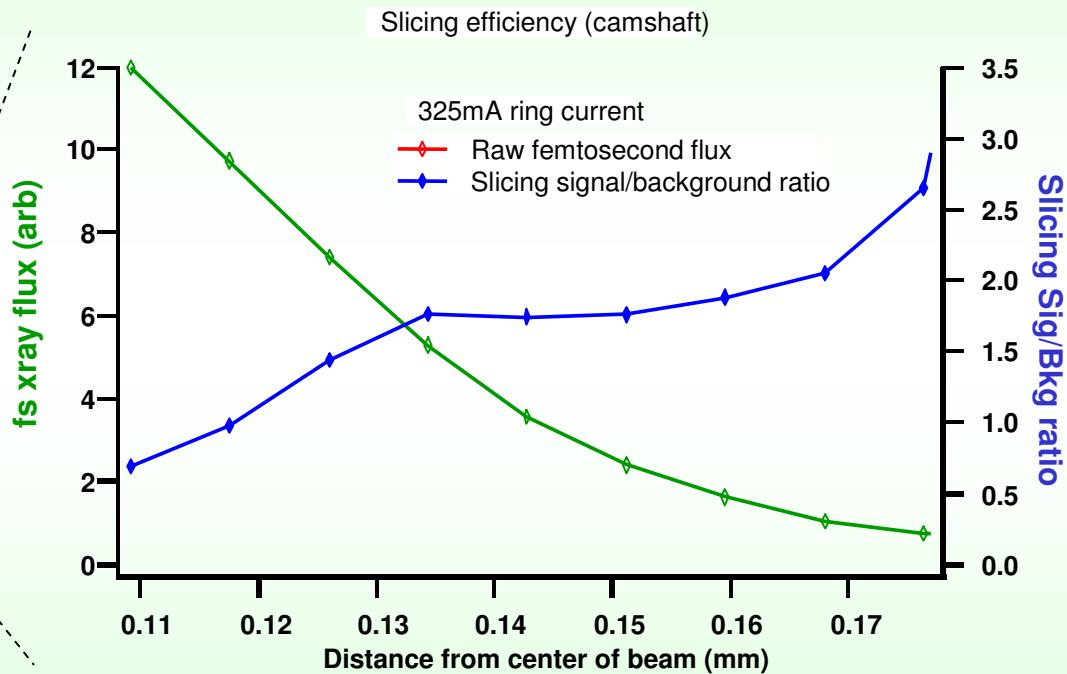


using gated detector



ALS e-beam:  
 $E_0 = 1.9 \text{ GeV}$   
 $\sigma_E \sim 1.9 \text{ MeV} (1 \times 10^{-3})$

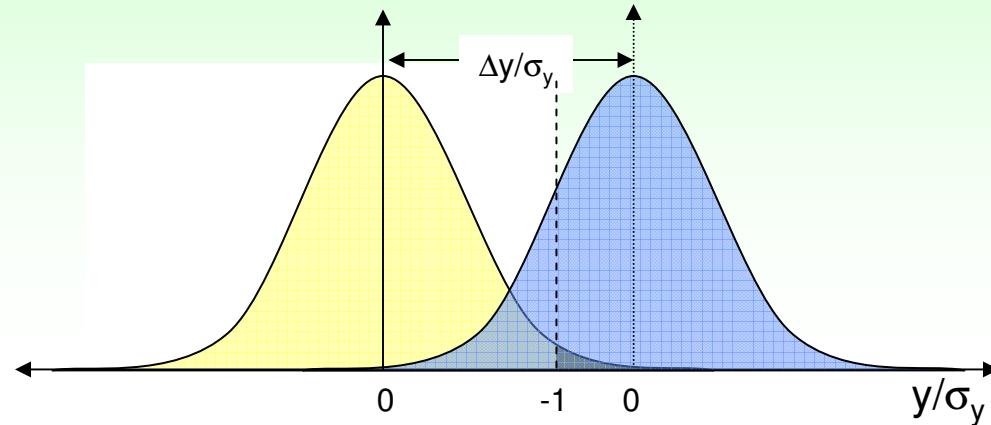
$$\Delta E \approx 17 \text{ MeV}$$
$$9\sigma_E$$



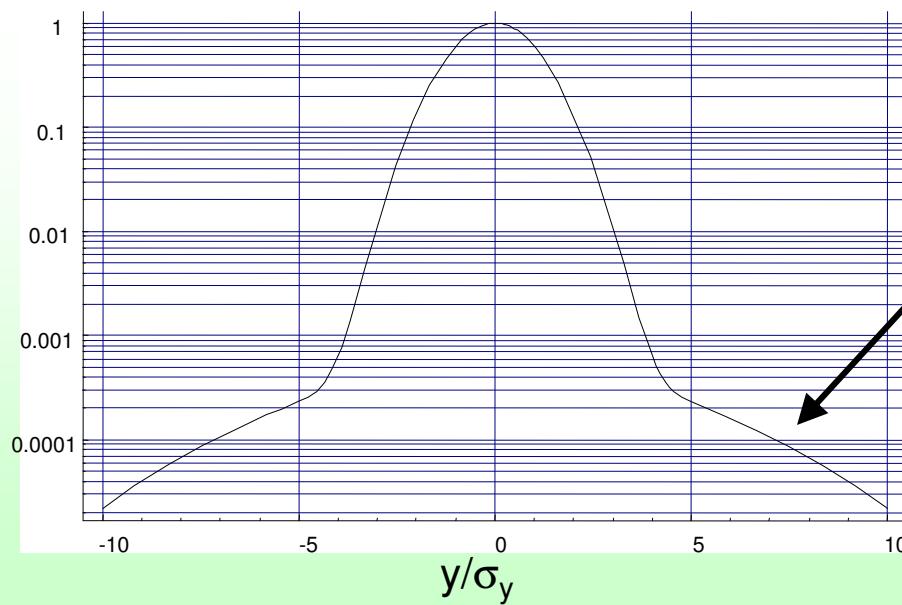
# Required Vertical Displacement for good background separation



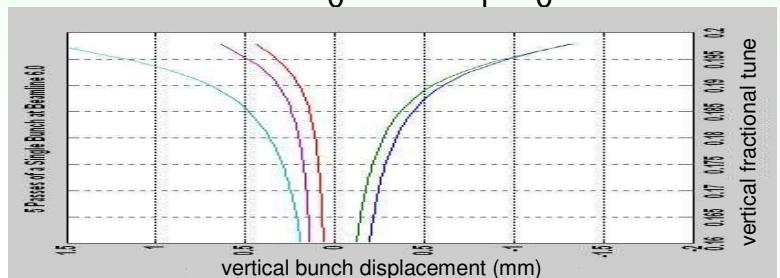
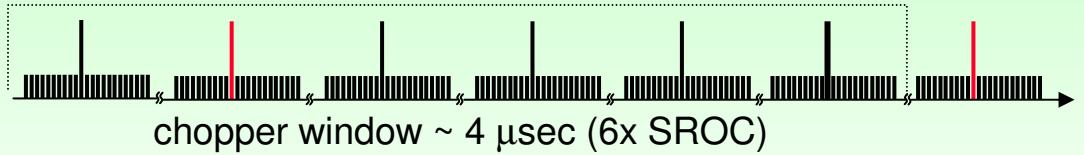
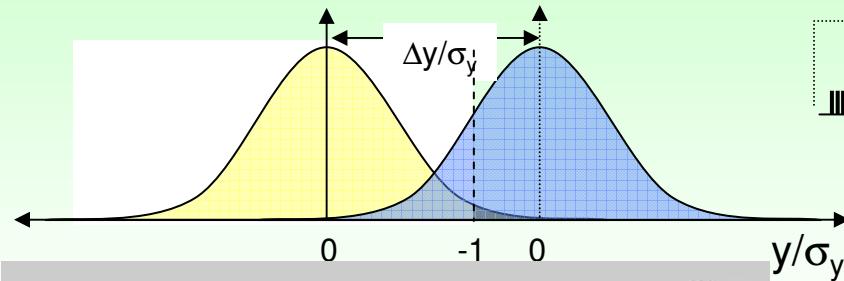
(full bunch duration)



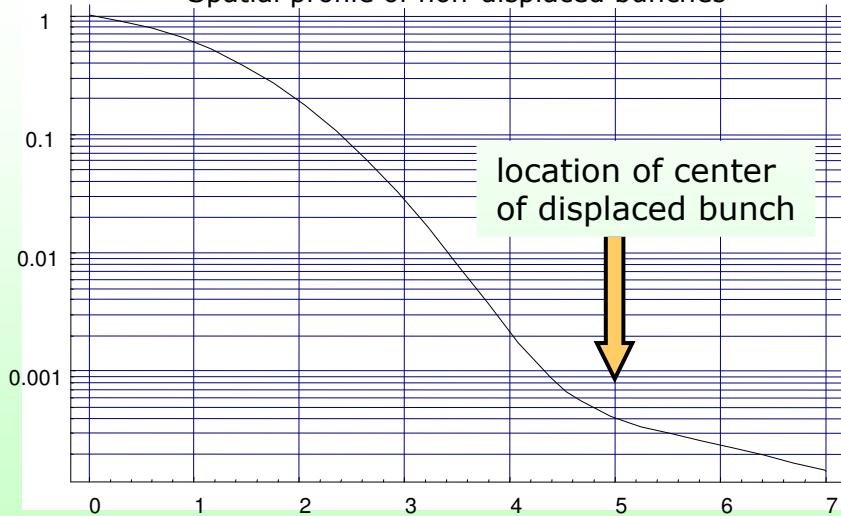
spatial beam  
intensity profile  
(approximate)



# Required Vertical Displacement and Sig/Bkg ratio (full bunch duration)



Spatial profile of non-displaced bunches



$\sim 5\sigma_y$  spatial displacement  
 $\sim 200 \mu\text{m}$  (straight 6)

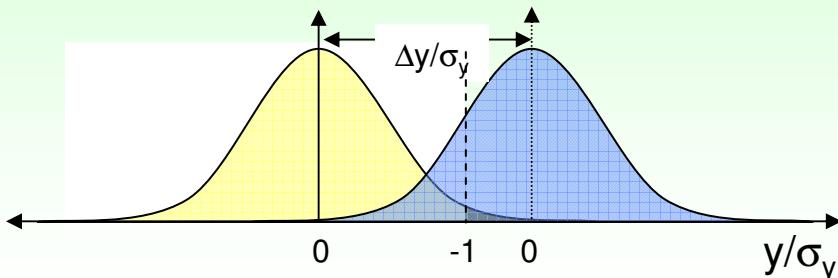
	Camshaft	Multibunches in chopper window (not displaced)	Other camshaft orbits (two of them are close)
Signal contribution	<b>10 mA</b>	-	-
Background contribution	-	6 round trips * 390mA * $4 \times 10^{-4}$ (@ $5\sigma_y$ ) <b>= <math>4.7 \times 10^{-1} \text{ mA}</math></b>	2 bunches * 10mA * $(2 \times 10^{-3}$ [@ $4\sigma_y$ ] + $1.5 \times 10^{-4}$ [@ $7\sigma_y$ ]) <b>= <math>4.3 \times 10^{-2} \text{ mA}</math></b>

$$\frac{\text{Sig}}{\text{Bkg}} = \frac{10 \text{ mA}}{5 \times 10^{-1} \text{ mA}} = \sim 20$$

at center of bunch

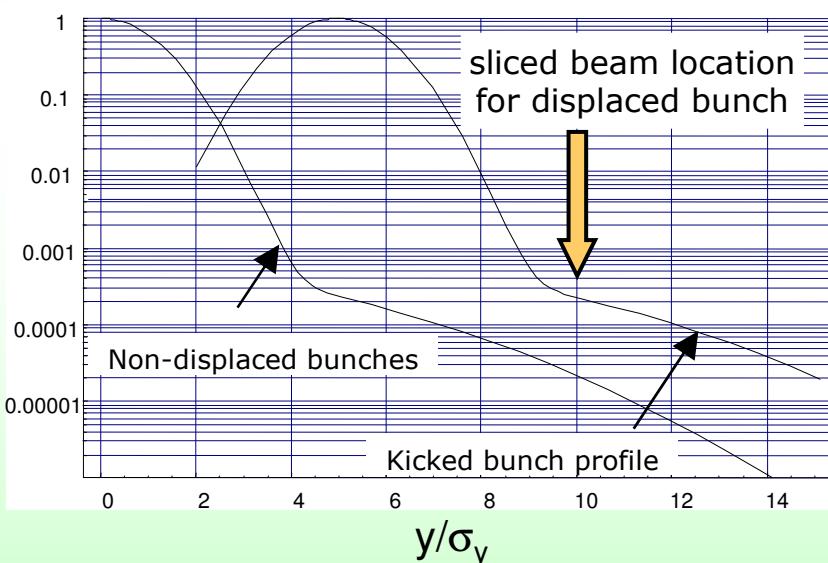
(assuming spatial wing profile shown on graph,  
and kicked bunch displacements from simulation)

# Required Vertical Displacement and Sig/Bkg ratio (sliced beam)



- stability of displaced beam ( $<<1\sigma$ )
- laser alignment to displaced beam in straight 5
- nonlinear dispersion,  $D_y$

$\sim 5\sigma_y$  spatial displacement  
 $\sim 200 \mu\text{m}$  (straight 6)



	Camshaft	Multibunches in chopper window (not displaced)	Other camshaft orbits (two of them are close)
Signal contribution	<b>10 mA * <math>2 \times 10^{-4}</math></b>	-	-
Background contribution	<b>10 mA * <math>2 \times 10^{-4}</math></b>	6 round trips * 390mA * $2 \times 10^{-5}$ (@ $10\sigma_y$ ) = <b><math>4.7 \times 10^{-2} \text{ mA}</math></b>	2 bunches * 10mA * $(7 \times 10^{-5} [@ 8\sigma_y] + 1 \times 10^{-5} [@ 11\sigma_y])$ = <b><math>1.6 \times 10^{-3} \text{ mA}</math></b>

$$\frac{\text{Sig}}{\text{Bkg}} = \frac{2 \times 10^{-3} \text{ mA}}{5 \times 10^{-2} \text{ mA}} = \sim 0.04$$

(assuming spatial wing profile shown on graph, and kicked bunch displacements from simulation)

# Summary



- Bunch kicks clearly observable at BL 6
- Displacement increases as fractional bunch kicking frequency approaches resonance
- bunch orbit may fluctuate close to resonance

- bunch kicking can reduce background from other bunches in picosecond operation
- challenges remain for fs slicing operation:
  - beam characterization far into the wings
  - better: larger bunch kicks,  
dispersion vs beam size & background,  
reducing wings of pulse

# Thanks to



## Beamline 6:

- Bob Schoenlein, Phil Heimann
- Bruce Rude, Nils Huse, Ernie Glover

